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Scale Covariant Cosmology and the Temperature of the Earth

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Summary. The changes in the temperature of the Earth as predicted by scale covariant cosmological models, that allow for a variation of G and M, are investigated.

Recent determination of the early temperature of the Earth seems to favor the case without matter creation.

Key words: Cosmology — Sun — Earth

Possible time evolution of the Earth's surface temperature, estimated today to be 286–288 °K, is of great interest (Newman and Rood, 1977; Wesson, 1973; Hoyle, 1972). Since it is known from stellar evolutionary computations that the Sun's luminosity was lower in the past by an amount ranging from 30 to 40%, it can be concluded that the Earth's temperature dropped below the freezing point of seawater less than 2.3×10^9 years ago (for $\Delta L = 50\%$) respectively. In addition, 4 to 4.5×10^9 years ago, the temperature was 263 °K and 245 °K respectively for $\Delta L = 30\%$ and 50%. These results correspond to a CO_2—H_2O greenhouse (Sagan and Mullen, 1972).

However, evidence (Sagan and Mullen, 1972) can be put forward which shows that (1) 3.2×10^9 years ago, liquid water must have been abundant (2) $3.2 \pm 0.1 \times 10^9$ years ago, blue-green algae existed and (3) 2.0 to 2.8×10^9 years ago, stromatolites (intertidal or subtidal) existed in different parts of the world. This is clearly at odds with the existence of temperatures near or below the freezing point of water.

The serious discrepancy has been circumvented by Sagan and Mullen upon postulating an alteration in the green-house components. Few parts per millions of NH_3 seem to alleviate the problem.

Against this background, one must now insert the possible variation of the Earth temperature due to the variation of the luminosity L not only because of stellar evolution but also because G and M can now vary as indicated by the scale covariant cosmology recently formulated by Canuto and collaborators (Canuto et al., 1977; Canuto et al., 1977).

We shall write in general

$$L(t) \sim L_{\mathrm{ev}}(t) G^{\gamma}(t) M^{\delta}(t) \quad (1)$$

where $L_{\mathrm{ev}}(t)$ accounts for time variants due to evolutionary effects, whereas cosmological effects are embodied in the variations of G and M. Knowing the variations of the absolute luminosity, we can compute the flux at the earth or solar constant, S

$$S = \frac{L}{4\pi R^2} \quad (2)$$

and consequently the time dependence of the "effective temperature[1],"

$$T_e(t) = \left[\frac{(1-A)S(t)}{4e\sigma}\right]^{1/4} = 210.69 S^{1/4}(t)\ ^\circ\mathrm{K} \quad (3)$$

where σ is the Stefan-Boltzmann constant, A the albedo (=0.35) and $e \approx 1$, the mean emissivity in the infrared. With L given by (1), we need only eliminate the orbit radius R in favor of G and M. Of the two "first integrals" derivable from the geodetic equations, the one representing the conservation of energy remains formally unchanged, whereas the one representing the conservation of angular momentum contains the scale factor $\beta(t)$. From Equation 4.19 of (Canuto et al., 1977), we have

$$R \sim \frac{1}{\beta^2 GM} \quad (4)$$

which in turn yields

$$S(t) = S_0 \left(\frac{L_{\mathrm{ev}}(t)}{L_0}\right) \beta^4(t) \left(\frac{G(t)}{G_0}\right)^{\gamma+2} \left(\frac{M(t)}{M_0}\right)^{\delta+2} \quad (5)$$

where S_0 is the solar constant today, 1.9885 cal cm^{-2} m^{-1}.

[1] The effective temperature of the Earth today is between 250°–255 °K, i.e., below the freezing point of seawater. The surface temperature $T_s \sim 287$ °K, can only be arrived at by including the greenhouse effect.

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We shall study four different cases:

(1) No cosmological evolution (β, M, G = const.)

$$S_1(t) = S_0\left(\frac{L_{ev}(t)}{L_0}\right). \tag{6}$$

(2) Primitive theory

M = const., β = const., $G \sim t^{-1}$, $R \sim t$

$$S_2(t) = S_1(t)\left(\frac{t_0}{t}\right)^{\gamma+2}. \tag{7}$$

(3) No matter creation (Canuto et al., 1977)

M = const., $\beta \sim t$, $G \sim t^{-1}$, $R \sim t^{-1}$

$$S_3(t) = S_1(t)\left(\frac{t_0}{t}\right)^{\gamma-2}. \tag{8}$$

(4) Matter Creation (Canuto et al., 1977)

$M \sim t^2$, $\beta \sim R^{-1} \sim t^{-1}$, $G \sim t^{-1}$

$$S_4(t) = S_1(t)\left(\frac{t}{t_0}\right)^{2\delta-\gamma-2}. \tag{9}$$

The corresponding effective temperatures are computed from Equation 3. Results are shown in Figures 1 and 2, for the case of Kramers ($\gamma = 7$, $\delta = 5$) and electron opacities ($\gamma = 4$, $\delta = 3$) and for $t_0 = 18.10^9$ yr, upon using the values of $L_{ev}(t)/L_0$ vs. t as from Table 1 (Stothers, 1977).

The dotted line corresponds to the work of Sagan and Mullen (1972), where they tried to lift curve (1) above the freezing point of seawater for at least a billion years via a greenhouse effect with CO_2 and H_2O. Neither Figure 1 nor Figure 2 represents the full story. In fact, it ought to be expected that the true opacities lie somewhere between the two extreme cases.

The true γ and δ can only be determined by performing a full numerical evaluation of the equilibrium stellar equations for the Sun, letting G and M vary. This has been done by Maeder (1977) and his results are

$$\gamma = 6.33 \qquad \delta = 4.86 \tag{10}$$

Table 1

Time (10^9 yr ago)	$L_{ev}(t)/L_0$
0.58	0.951 (4%)
1.2	0.908 (9)
1.83	0.866 (13)
2.48	0.827 (17)
3.14	0.793 (20)
3.79	0.764 (24)
4.12	0.747 (25)
4.28	0.736 (26)
4.36	0.721 (28)
4.40	0.709 (30)

When such values are substituted in (6)–(9), we obtain the results shown in Figure 3, where the four stars correspond to recent experimental points due to Knauth and Epstein (1976).

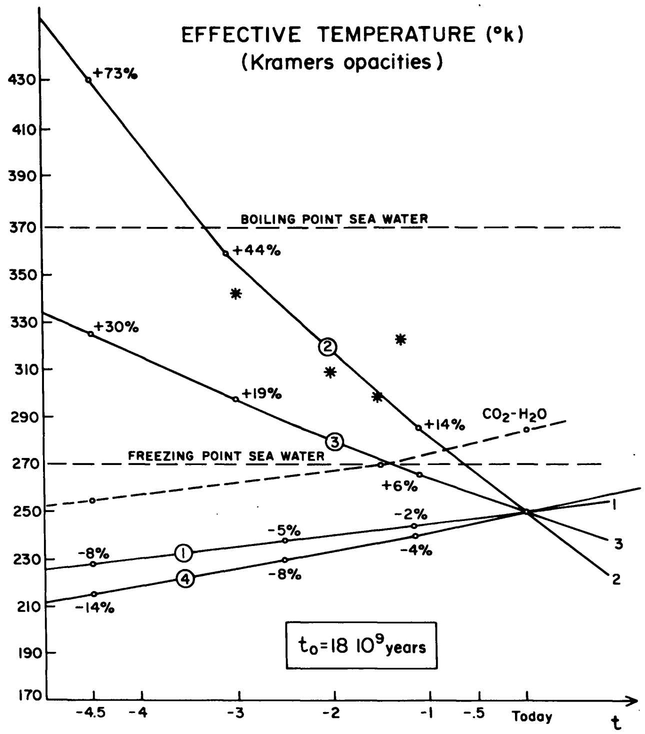

Fig. 1.

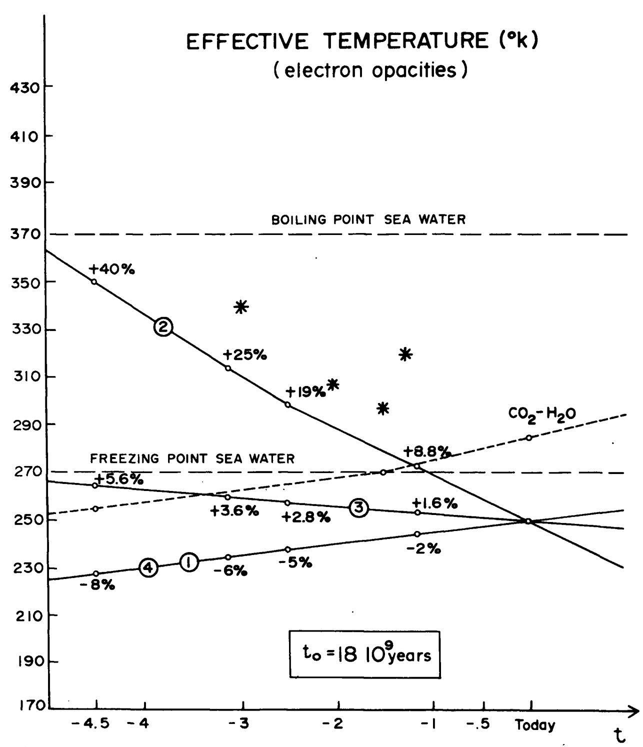

Fig. 2.

Conclusions

It is seen from Figure 3 that the cases with and without matter creation yield significantly different temperature profiles.

In (Canuto et al. 1976) it was concluded that the most recent determination of $\dot{G}/G$ is in accord with the present theory, only if case (4) is adopted. If we give priority to $\dot{G}/G$ over geological evidence, then curve 4 can be lifted only be a greenhouse mechanism. Sagan (1977), in view of Knauth and Epstein's (1976) new results, has recently shown that, all other things being equal, a primitive atmosphere rich in H_2 is even a better candidate than the one containing NH_3. In the case of matter creation, we would therefore have to resort to the same mechanism.

However, if one gives a higher priority to geological data over the determination of $\dot{G}/G$, we would conclude that Knauth and Epstein data definitely favor the non-matter creation case. In fact a CO_2–H_2O greenhouse alone would already lift case 3 of Figure 3 to make it go through the experimental points.

This would imply that the atmosphere of the Earth did not significantly change its main composition over several billion years.

To the best of our knowledge, this is the first time that geological data can be used to infer considerations of cosmological significance.

Since the data accumulated so far (Canuto et al., 1977) have not yet unequivocably tilted the balance in favor of case (3) or (4), geological data could become, if definitely confirmed, a major cosmological discriminator.

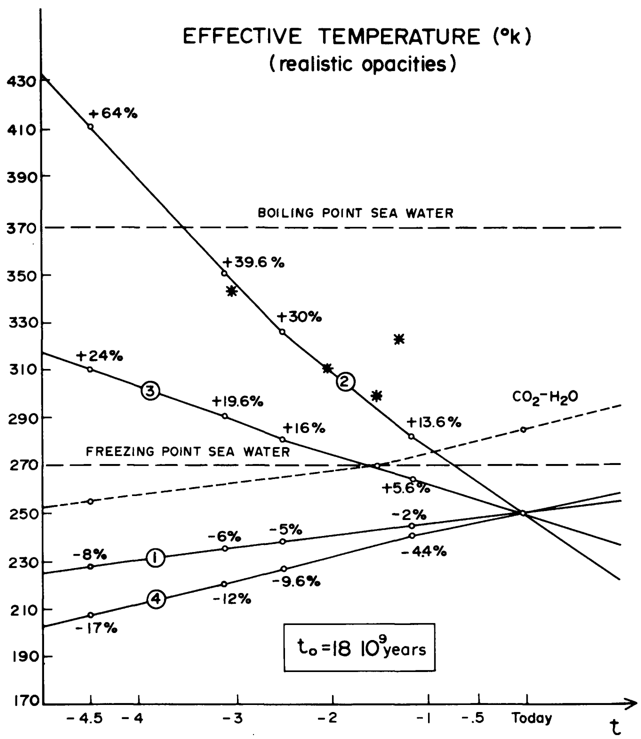

Fig. 3.

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